Flow around steep topography

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LONG-TERM GOALS

Strong westward flow in the North Equatorial Current (NEC) encounters tall, steep, submarine topography and islands. During the Flow Encountering Abrupt Topography (FLEAT) DRI, investigators will determine:

- Whether appreciable energy/momentum is lost from the large-scale NEC flow to smaller scales and through which processes?
- What limits numerical models/state estimates from making accurate statistical/deterministic predictions at $<$10 km resolution around submarine topography and islands? How can we improve them?

OBJECTIVES

In cooperation with other FLEAT investigators, observations and model results will be examined up- and downstream of topography to address two overarching hypotheses:

- Energy and momentum are lost in appreciable amounts due to encounters between low-frequency flows and topographic features that are not well/explicitly resolved in regional models. This would happen through a combination of (i) quasi-linear processes (e.g. form drag, lee waves, eddy generation) over small-scale topographic features and (ii) fundamentally nonlinear processes (turbulent island wakes).
- Downscaling model fidelity may be considerably improved by combination of focused numerical process studies, inclusion/assimilation of new in situ data densely spaced around topography, and better dynamical understanding of the key physical processes.

APPROACH

Cruises in 2013 and 2014 obtained spatial surveys of currents and hydrography. These 2014 surveys were made with SeaSoar, which was towed from R/V *Revelle*. Currents (denoted u and v, which are positive east- and northward), potential temperature (θ), and salinity (S) were obtained from *Revelle*'s Doppler sonars and SeaSoar (an undulating vehicle equipped with a conductivity-temperature-depth instrument or CTD). SeaSoar completes a dive cycle from 5–400 m every ∼10 minutes or ∼3 km while being towed at 8 knots. Shipboard Doppler sonars included the Hydrographic Doppler Sonar System (HDSS) with 50 and 140 kHz systems for profiling to ∼700 and 300 m as well as an RDI Ocean Surveyor (OS) 75 kHz acoustic Doppler current profiler (ADCP) and a narrowband 150 kHz ADCP. In 2013, an underway CTD (UCTD) was used, which is described in detail in another annual report.

From 9 October to 12 November 2015, another SeaSoar cruise on *Revelle* will focus on wakes and arrested lee waves near Yap Island in the Federated States of Micronesia and the north/south points of the main islands of Palau as a contribution to FLEAT (Figure 1). There is sufficient time to repeat some of the radiator patterns. A mooring with ADCPs and T-C sensors will be deployed in about 300 m of water at a submarine ridge for Mark Merrifield (UH). An anchor for a waverider buoy will also be deployed on the east coast for Eric Terrill (SIO).

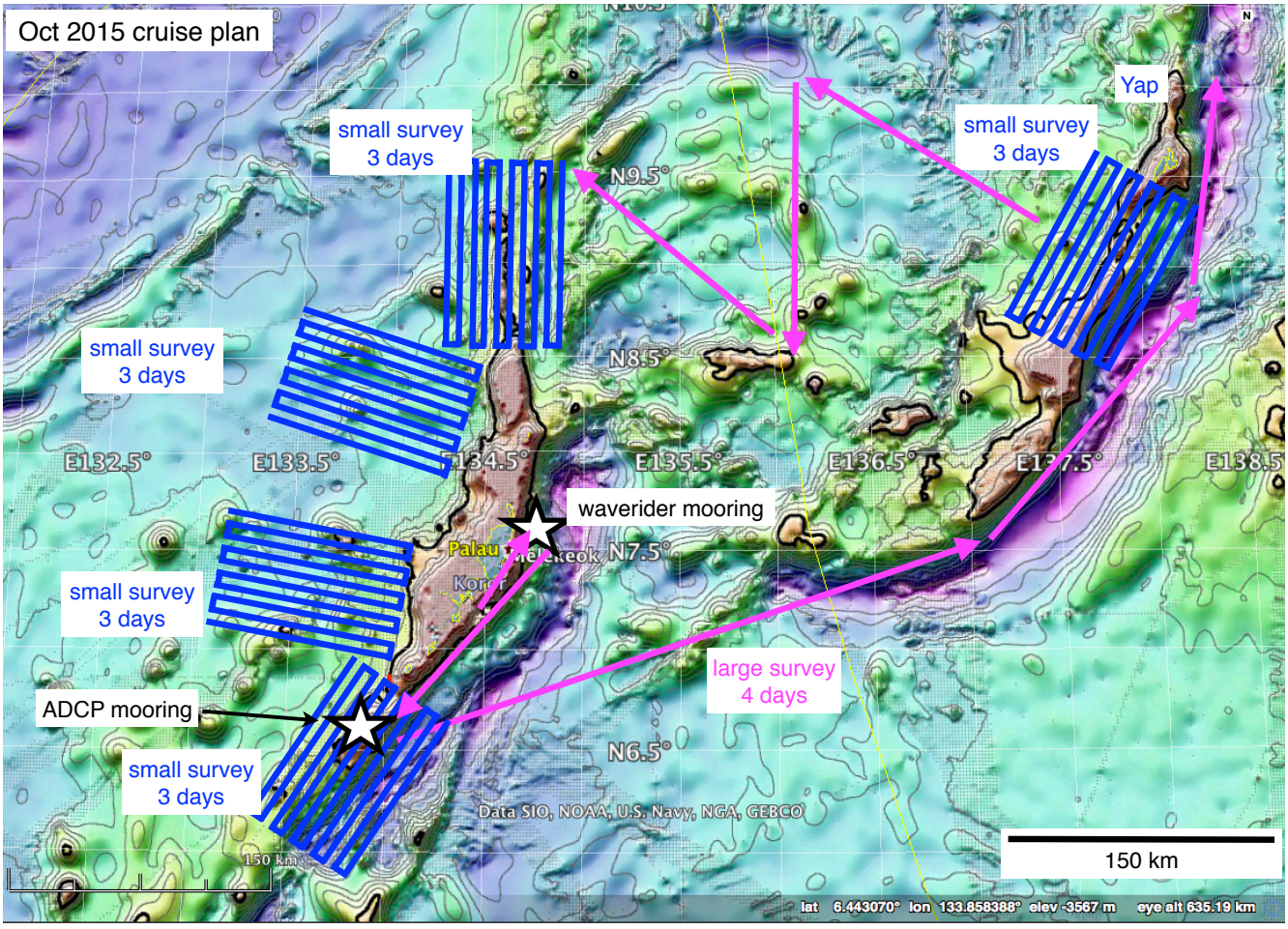

Figure 1: Moorings will be deployed. Then SeaSoar will survey in at least 5 radiator patterns: (1) at Yap and (2–5) south, north, northwest, and southeast of the main islands of Palau.

WORK COMPLETED

Graduate education

Celia Ou, a graduate student starting her third year, has quality controlled the data from the 2013 and 2014 cruises and is focusing her analysis on the arrested lee waves with the intention of presenting these results at the Ocean Sciences meeting in 2016. These data will form the basis of her thesis. She will gain at-sea experience on the upcoming cruise and apply her analysis to these data.

In addition, 4 other Scripps graduate students will be joining the 2015 cruise as watch standers to gain at sea experience.

Cruise preparation

A new tow cable was faired over 2 weeks by Scripps Shipboard Technical Support (STS) and graduate students who are joining the upcoming cruise. Two complete SeaSoar units and ancillary gear were prepared and shipped recently to Palau for the upcoming cruise by STS.

Outreach

We will provide tours of *Revelle* to high school students and the US ambassador to Palau. Capt. Murline has expressed ongoing interest in these activities. These tours are being coordinated with the Coral Reef Research Foundation (CRRF), a research organization in Palau.

Cory Tamler, a writer, will be joining the cruise, participating in the work, and using this experience as a basis for a writing project.

RESULTS

The science plan (long-term goals, objectives, and logistics) for FLEAT was formulated at a meeting in June 2015 at Scripps. A range of phenomena from small to large space and time scales scales (i.e., from turbulent mixing to strong zonal low-latitude currents) will be the focus of modelling and observational activities (Figure 2).

Analysis from previous cruises funded under another grant provided confirmation that these processes are energetic in this area. The upcoming SeaSoar cruise will focus on arrested internal lee waves, island wakes, and meso- and submesoscale eddies/fronts.

IMPACT/APPLICATIONS

While internal tides have energy conversion rates of $\mathcal{O}(100\ \text{mW m}^{-2})$ in the western Pacific, little energy is lost from the barotropic tide in the vicinity of Palau (Egbert and Ray, 2003). However, geostrophic flow over the abrupt topography may input $\mathcal{O}(0.1\text{–}100\ \text{mW m}^{-2})$ into lee waves in a patchy pattern below 10°N in the waters of Palau and the Federated States of Micronesia according to estimates by Nikurashin and Ferrari (2013). The lee wave energy estimates are based on modelled geostrophic flow and Smith-Sandwell bathymetry, which may underestimate the roughness on the scales of rough topography in the western Pacific (Smith and Sandwell, 1997). “Their theoretical argument for the global importance of lee-wave breaking is provocative and intriguing. However, the quantitative part of their conclusion is subject to several uncertainties. The largest issue is the paucity of

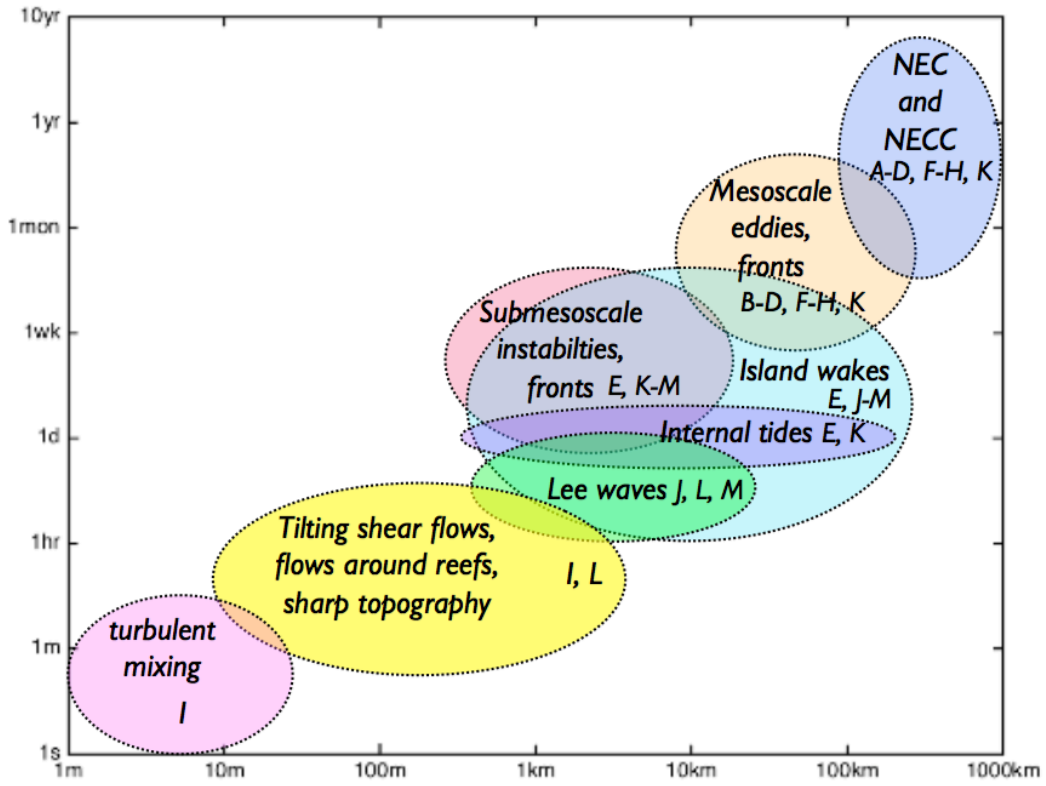

Figure 2: Some physical phenomena of interest over a range of time and space scales. Letters denote various models and modelling domains used in FLEAT. Figure from the FLEAT Science Plan.

direct observations of lee-wave generation, propagation and turbulent breaking in the deep or abyssal ocean," notes (MacKinnon, 2013). Further analysis of the these data may help with understanding how relevant lee wave generation and propagation are in this region of rough topography (i.e. tall, isolated seamounts and ridges that extend into the thermocline). Unlike the Southern Ocean where the lee waves occur over much smaller abyssal hill topography, the western Pacific contains more isolated, tall submarine topography- i.e., seamounts and ridges, which extend into the thermocline. Lee wave effects may be quite important locally, but not resolved or visible on a global map.

Based on results from previous cruises and other work by Chang et al. (2013) at islands in the Kuroshio, turbulent island wakes display high vertical shear and strong lateral gradients, which means Richardson numbers are low and vorticity, strain, and Rossby number are large. This indicates island wakes and eddies generated at points play a role in removing energy from the incident, low frequency flows.

RELATED PROJECTS

There are a number of related projects: (a) state estimates of the tropical Pacific are being made (Bruce Cornuelle, SIO; Brian Powell, UH), (b) coastal measurement arrays around Palau have been deployed (Eric Terrill, SIO), and (c) gliders have repeated cross-shore sections around Palau (Dan Rudnick, SIO). All of these datasets and the 2013 and 2014 cruise data will be useful for producing state estimates in the tropical Pacific and assessing the importance of lee waves and island wakes. (The 2013 and 2014 cruises were funded from the core Physical Oceanography program.) The state estimates will also be

essential for understanding how boundary currents depend on the upstream conditions via an island rule calculation (Godfrey, 1989) versus episodic eddy arrivals at a topographic obstacle. Furthermore, Cornuelle and Powell will provide results from state estimates to help guide sampling during the 2015 *Revelle* cruise.

A DURIP award was received for UCTD system, which will be deployed regularly as a component of FLEAT from CRRF's coastal research vessel in 2016-17 to make spatial surveys of eddies and wakes generated at points in conjunction with the remotely-operated surface sampler (ROSS; Jonathan Nash, OSU) and the coastal measurement array (Terrill). A proposal was prepared and is currently being evaluated for ship time on *Falkor* to use the UCTD in 2017 for FLEAT.

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